March 29, 1966 J. C. HOLTZMAN 3,243,818

DUAL BAND SLOT ANTENNA HAVING COMMON WAVEGUIDE WITH DIFFERING SLOTS, EACH INDIVIDUAL TO ITS OWN BAND

Filed Aug. 22, 1962 4 Sheets-Sheet 1

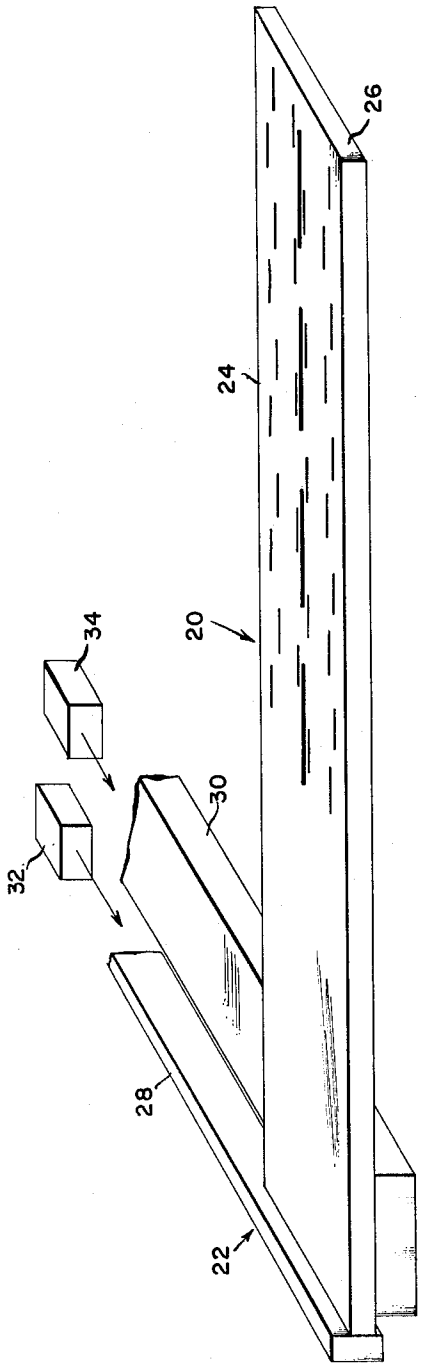

Fig. 1.

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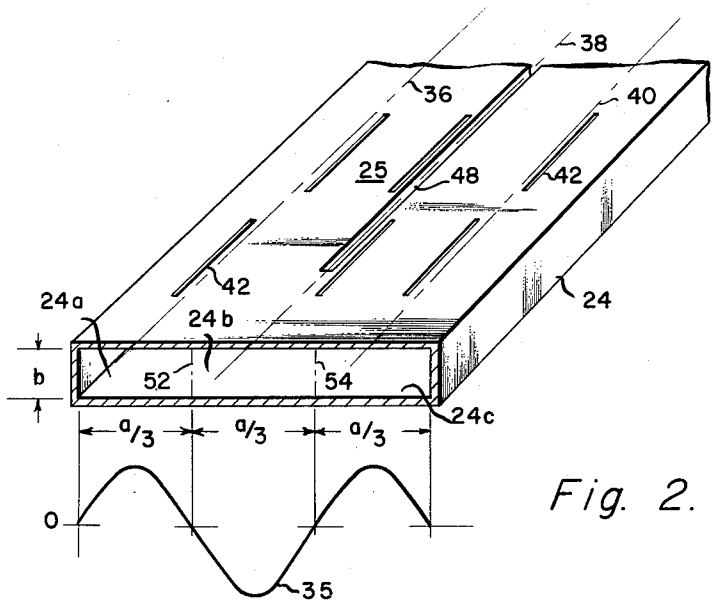

Fig. 2.

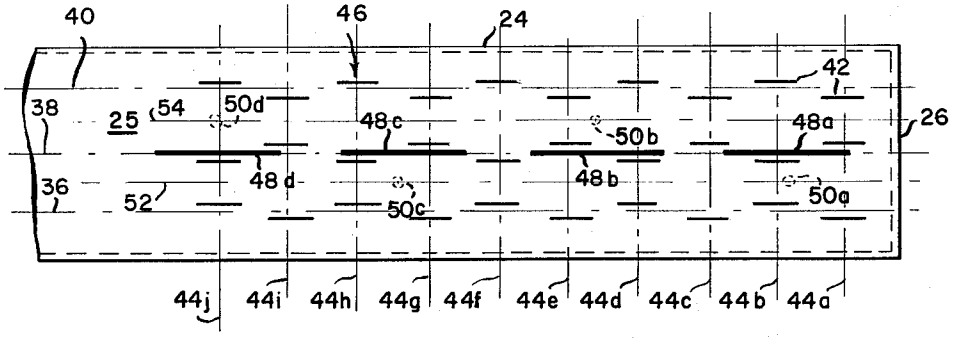

Fig. 3.

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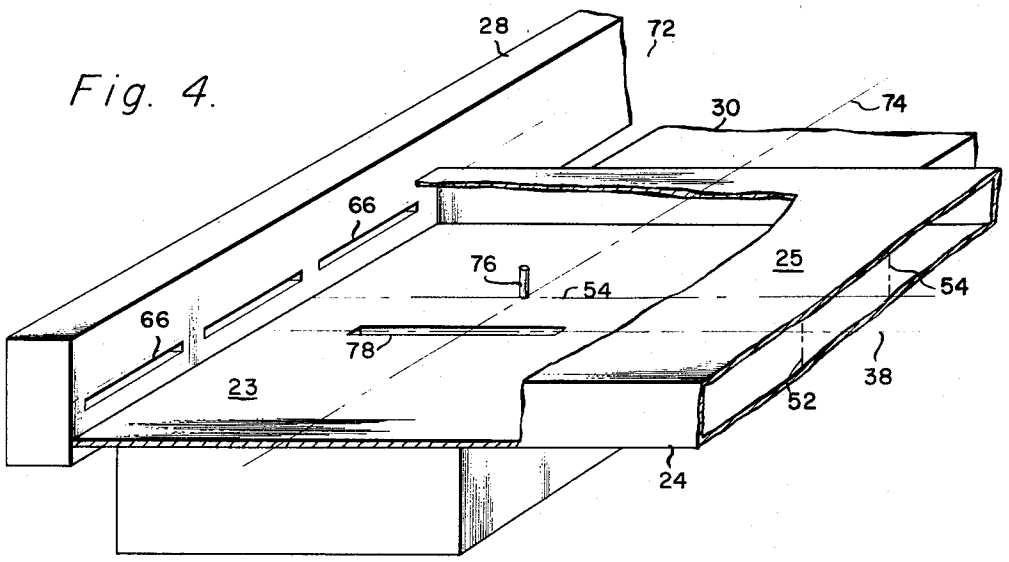
Fig. 4.



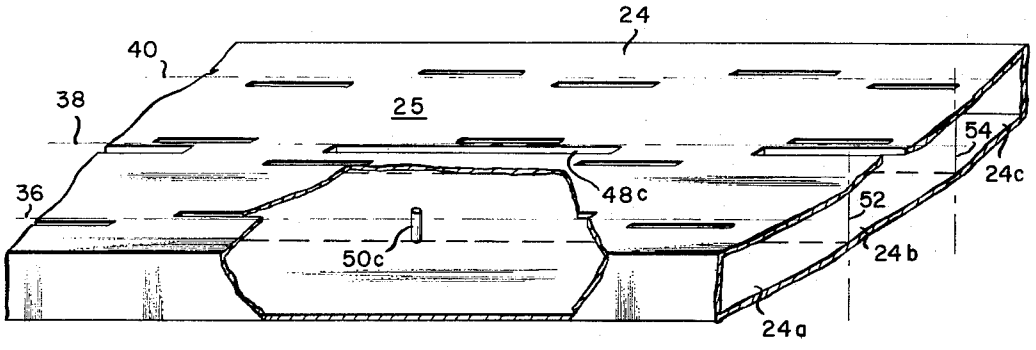


Fig. 5.

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Filed Aug. 22, 1962 4 Sheets-Sheet 4

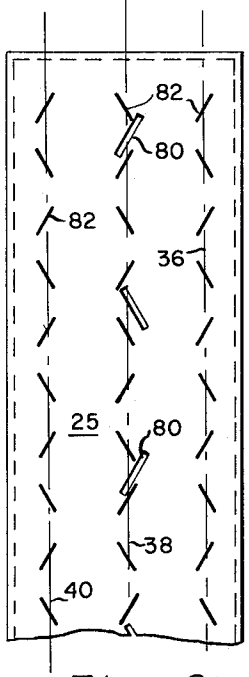

Fig. 6.

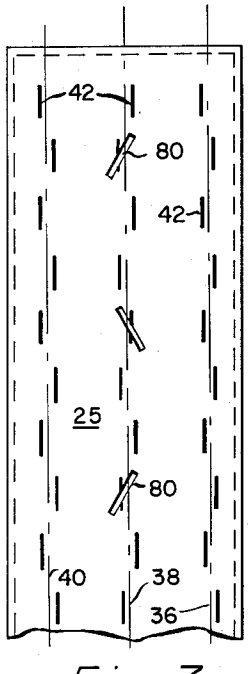

Fig. 7.

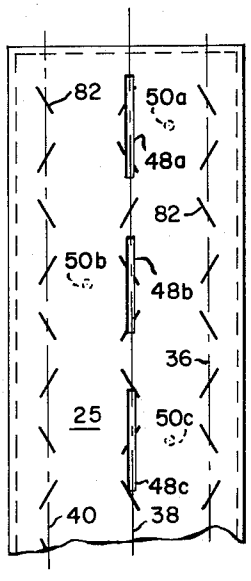

Fig. 8.

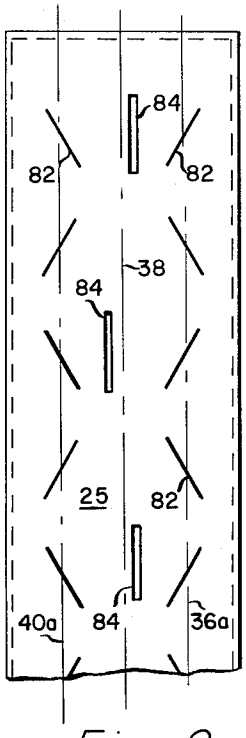

Fig. 9.

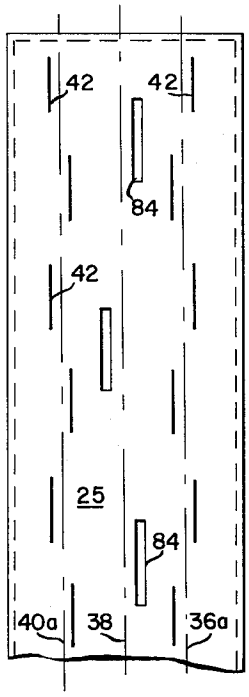

Fig. 10.

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United States Patent Office 3,243,818 Patented Mar. 29, 1966

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DUAL BAND SLOT ANTENNA HAVING COMMON WAVEGUIDE WITH DIFFERING SLOTS, EACH INDIVIDUAL TO ITS OWN BAND

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Filed Aug. 22, 1962, Ser. No. 218,603
15 Claims. (Cl. 343—771)

This invention relates to a slot antenna and more particularly to a dual band array of interposed slots in the broad wall of a single waveguide.

In systems employing microwave antennas, it is frequently desirable and often necessary to transmit or receive two signals at widely spaced frequencies. When both terminals of such a system are located on the earth, no difficulties are encountered in the antenna portion of the design. Separate antennas, spaced so as not to interfere with one another, may be used and are generally most satisfactory. However, in airborne, and especially in satellite applications, the space and weight requirements make the antenna design one of the critical factors in the success of such a system.

In some instances, multiband operation has been achieved by employing two antennas which are isolated from each other. However, this has usually been achieved at the expense of gain since the total aperture has to be divided between the two channels. A more desirable design would provide common use of the total available aperture in such a fashion that either or both channels could be used for transmission or reception without mutual interaction.

In other instances, compound feed horns illuminating parabolic reflectors have been used for multiband operation. But, this too does not solve the problem of generating isolated beams at two widely separated frequencies from a single aperture. The reason primarily is aperture blockage, a problem in most reflector antenna designs. At widely separated frequencies, aperture blockage becomes prohibitive since the lower frequency feed presents an extremely large obstacle to the higher frequency, thereby causing degradation of the pattern and gain.

A slot array, on the other hand, does not have the aperture blockage problem which is associated with the reflector antennas. Accordingly, one solution of problems associated with multiband operation is an array of interlaced waveguides for each frequency provided the interslot spacing requirement, (less than λ_0), is satisfied. With such spacing, a single main beam may be generated. However, weight and space requirements, usually very stringent in airborne and satellite systems, dictate an approach utilizing the least possible number of waveguides.

Recently, a planar array antenna comprising several rows of slots machined in the broad wall of a waveguide operating in a higher mode was disclosed in the literature. (See McCormick, G. C., "A Two Dimensional Slotted Array," IRE Trns. PGAP, vol. 6, January 1958, pp. 26–35). This represents an advancement in the art to the extent that the array is confined to a single waveguide. However, the operation of this planar array antenna was not extended to multiband operation. Therefore, such an antenna is not a solution to the present problem.

In the present invention the slot is also used as a radiating element. Thus, the phase and amplitude of the current radiating from each slot can be accurately established as desired by varying either the angle of inclination of the slot or its displacement from the waveguide center line. As a result, clumsy and bulky phase shifting and impedance matching elements are eliminated.

With this invention, the above mentioned disadvantages are overcome and the advantages of the slot as a radiating element are utilized to the fullest. Accordingly, the present invention provides an array of slots which

can transmit and receive signals in different bands, as for example the S- and X-bands, through a single planar aperture. In addition, several such arrays may be grouped in a conventional manner to form a planar array operating at two widely separated frequencies while still retaining adequate channel separation.

According to the present invention, there is provided a dual band slot antenna comprising a single waveguide structure capable of supporting the propagation of energy at two widely separated frequencies, one in a higher order mode than the other. An array of slots is disposed in the broad wall of the waveguide, certain of these slots appearing invisible to the lower frequency energy and the remaining slots coupling only negligibly with the higher frequency energy. The result is essentially placing two antennas in the space otherwise occupied by one.

It is therefore a principal object of the present invention to provide a slot array antenna of the type to be described which is capable of transmitting and receiving signals at widely separated frequencies from a single waveguide.

The above and other features, objects and advantages of the present invention will appear from the following description of an exemplary embodiment thereof illustrated in the accompanying drawings wherein:

FIG. 1 is a perspective view of a dual band slot antenna of the invention;

FIG. 2 is a perspective view showing a cross section along lines 2—2 of the antenna of FIG. 1;

FIG. 3 is a plan view of the preferred geometrical arrangement of slots in an antenna of the invention;

FIGS. 4 and 5 are partial perspective views of portions of the antenna of FIG. 1;

FIGS. 6 through 10 are plan views showing alternate slot arrangements which may be incorporated in the antenna of FIG. 1.

Referring to FIG. 1, a dual band slot antenna **20** is shown having a waveguide **24** adapted to propagate electromagnetic waves at two widely separated frequencies, the lower frequency waves in a TE_{no} mode and the higher frequency waves in a higher order TE_{mo} mode. In a preferred embodiment described below, the waveguide **24** supports electromagnetic waves in the TE_{10} and the TE_{30} modes, the center frequencies of these waves being 3010 and 8600 megacycles respectively. Energies supported in other combinations of modes and at frequencies in either the same respect S- and X-bands or other bands, may be transmitted and received by slot antennas of the type to be described by modifying the slot array in accordance with this invention.

The waveguide **24** includes a broad wall **25** having an array of radiating slots disposed therein and a terminating end wall **26**. A matched load may be used in lieu of the end wall **26** to obtain a traveling wave array, if desired. A waveguide assembly **22** comprising feed waveguides **28** and **30** is provided for propagating electromagnetic waves from, for example, signal generators **32** and **34** respectively and for introducing these waves to the dual band slot antenna **20**. Hereafter, the electromagnetic waves which are propagated through the feed waveguide **28** and which are coupled to and supported by the waveguide **24** in the TE_{30} mode are referred to as the higher frequency waves. The electromagnetic waves which are propagated through the feed waveguide **30** and which are coupled to and supported by the waveguide **24** in the dominant TE_{10} mode are referred to as the lower frequency waves.

In FIG. 2, a curve **35** is shown representing the transverse electric field distribution of the electromagnetic wave propagated in the TE_{30} mode through the waveguide **24**. At two points along the curve **35**, it will be noted that the electric field is zero. Therefore, propagation through

the waveguide **24** in the TE_{30} mode may be considered as several, adjacent waveguides each carrying only the TE_{10} mode. Phrased differently, the waveguide **24** of FIG. 2 may be viewed as comprising three virtual waveguides **24***a*, **24***b* and **24***c* arranged side by side except that the inner side walls **52** and **54** which are common to the virtual waveguide **24***b* are missing. It should also be noted that in FIG. 2 the center lines of the virtual waveguides **24***a*, **24***b* and **24***c* become the lines **36**, **38** and **40** respectiely when projected onto the broad wall **25**. In the preferred embodiment of FIG. 2, the height "*b*" and the width "*a*" of the waveguide **24**, for example, are 0.400" and 2.700" respectively.

FIG. 3 shows an array **46** of interposed slots **42** and **48** disposed in the broad wall **25** of the slot antenna **20**. Slots **42** are shunt slots resonant at the higher frequency and are displacement coupled to the TE_{30} mode. The resonant frequency of the slots **42** is sufficiently above the lower frequency that, for all practical purposes, no energy propagated at the lower frequency is radiated by the slots **42**. Slots **48** are longitudinal centered slots resonant at the lower frequency and are probe coupled to the TE_{10} mode by the probes **50**. By placing the probes **50** in the plane of the virtual side walls **52** and **54** of the virtual waveguides **24***a*, **24***b* and **24***c*, the TE_{30} mode is unaffected. However, the probes **50** interact with the TE_{10} mode to excite the slots **48**. Since the slots **48** are located on a center line of the TE_{30} mode, energy propagated in this mode is not radiated by the slots **48**.

The array **46** of FIG. 3 comprises three rows of shunt slots **42** arranged in 10 columns **44***a*, **44***b*, **44***c* . . . **44***j*, each column being spaced along the waveguide **24** at points where the high frequency shunt current is a maximum, in other words, at odd-multiples of high frequency quarter-wavelengths as measured from the inner surface of the end wall **26**. By displacing adjacent slots **42** in each column and in each row on alternate sides of the lines **36**, **38** and **40** as shown in FIG. 3, each slot radiates energy in like phase to form a beam and the TE_{30} mode purity is maintained.

In the preferred embodiment, the slots **48**, for example, are 0.058" wide and 1.968" long and are spaced 2.873" apart along the center line **38** of the waveguide **24**, the slot **48***a* being 1.437" from the inner surface of the end wall **26**. The slots **42** similarly are 0.040" wide and 0.676" long and are displaced 0.065" from their respective center lines **36**, **38** and **40**. The columns **44** of shunt slots **42** are spaced 1.056" apart, the column **44***a* being 0.528" from the inner surface of the end wall **26**. It should be noted that the shunt slots **42** are transversely displaced an equal amount about the corresponding lines **36**, **38** and **40**. This geometry results in a slot array having a uniform amplitude taper. By varying this transverse displacement of some or all of the slots **42**, a desired non-uniform taper may be achieved.

FIG. 4 shows one method of coupling the higher and lower frequency waves from the feed waveguides **28** and **30** respectively to the slot antenna **20**. The feed waveguide **28** includes a broad wall **27** in which shunt slots **66** are placed along one side of the center line **72** of the feed waveguide **28**. In addition, the slots **66** are resonant at the higher frequency and have their centers aligned with the centers of the virtual waveguides **24***a*, **24***b* and **24***c*, reference FIG. 5. At the lower frequency, that portion of the broad wall **27** which traverses the waveguide **24** appears as a continuous surface. A common wall **23** is defined by the broad walls of the waveguide **24** and the feed waveguide **30**, which waveguides **24** and **30** are shown having their respective center lines **38** and **74** orthogonal to each other. A longitudinal slot **78** extends along the center line **38** and has its center at the junction of the center lines **38** and **74**. The slot **78** is resonant at the lower frequency and is coupled by a probe **76** to the lower frequency waves to launch the TE_{10} mode in the waveguide **24**. Higher frequency energy is not radiated by the slot **78** since it is centered along a center line of the TE_{30} mode and the probe **76** is located along the center line **74** and in a plane where the transverse electric field in the TE_{30} mode is zero.

In the partial perspective of FIG. 5, a probe **50***c* is shown located at the junction of the virtual side wall **52** and a transverse plane passing through the center of the slot **48***c*. Each of the other probes **50** is similarly located. It should be noted that the TE_{30} mode is unaffected by the presence of the probes **50** since the transverse electric field in the TE_{30} mode is zero in the plane of the virtual side walls **52** and **54**. The probes **50**, however, constitute a neighboring discontinuity at the lower frequency and excite the slots **48**. The degree of slot coupling at the lower frequency may be regulated by the geometry of the probes **50** and their extension into the waveguide **24**.

FIGS. 6 through 10 show slot arrays constituting alternate embodiments of the present invention. These arrays are made up of different combinations of high and low frequency slots. In the arrays of FIGS. 7 and 10, the higher frequency waves are radiated by shunt slots **42** and in the arrays of FIGS. 6, 8 and 9 by series slots **82**. The lower frequency waves are radiated by dielectrically loaded series slots **80** in the arrays of FIGS. 6 and 7, by probe coupled centered slots in the array of FIG. 8, and by dielectrically loaded shunt slots in the arrays of FIGS. 9 and 10.

The higher frequency shunt slots **42** of FIGS. 7 and 10 are similar in all respects to the slots **42** of FIGS. 2, 3 and 5.

The higher frequency series slots **82** of FIGS. 6, 8 and 9 are resonant at the higher frequency and are spaced along the broad wall **25** in regions where the high frequency series current is maximum. This occurs at even multiples of higher frequency quarter-wavelengths from the end wall **26**. The center of the series slots **82** lie along lines **36**, **38** and **40** in FIGS. 6 and 8 and in FIG. 9 along the lines **36***a* and **40***a*. The degree of coupling of the series slots **82** to, for example, the TE_{30} mode in the case of FIGS. 6 and 8 is regulated by the amount of inclination of the slots **82** to a center line of the TE_{30} mode. An analogous statement is applicable to the coupling of the series slots **82** shown in FIG. 9 to the TE_{20} mode.

The low frequency slots **80** and **84** of FIGS. 6, 7, 9 and 10 are dielectrically loaded. Disposing a material, for example commercially available "Stycast" or "Eccofoam," having a desired dielectric constant in an open slot permits reducing its physical length without altering its initial electrical length. Thus, an open slot resonant at some frequency may be reduced in length, filled with the dielectric material and still be resonant at the same initial frequency. Slots **80** and **84** may be dielectrically loaded in this manner.

In the array shown in FIGS. 6 and 7, the dielectrically loaded series slots **80** have their centers spaced along the center line **38** at points where the high frequency series current is a minimum. At these points, only a negligible amount of higher frequency energy will be radiated by the shortened low frequency series slots **80**.

In FIG. 8, the low frequency slots are longitudinal centered slots **48** which are probe coupled to the low frequency energy by the probes **50**. In this respect, the array of FIG. 8 is similar to the array **46** of FIG. 3.

The low frequency dielectrically loaded shunt slots **84** of FIGS. 9 and 10 are alternately spaced on either side of the center line **38** at points where the high frequency shunt current is a minimum. At these points, only a negligible amount of higher frequency energy will be radiated by the shortened low frequency shunt slots **84**. The slots **84** are displacement coupled to the low frequency wave in a manner similar to the higher frequency shunt slots **42** described above.

It should be pointed out that the slot arrays of FIGS. 9 and 10 each illustrates an array in which the higher

frequency waves are supported in waveguide 24 in the TE_{20} mode.

Thus, there has been described a dual band slot antenna comprising a single waveguide structure capable of supporting the propagation of energy in higher order modes at widely separated frequencies. The slot antenna may have a beam pattern having either a uniform or a non-uniform amplitude taper.

While several embodiments of the invention have been shown and described, other modifications may be made and it is intended that the foregoing disclosure shall be considered only as illustrative of the principles of the invention and not construed in a limiting sense.

What is claimed is:

1. A dual band slot antenna comprising a waveguide structure having a broad wall; means for coupling to said structure a first electromagnetic wave having a frequency within a first band and a second electromagnetic wave having a frequency within a second band; a first slot disposed in said broad wall and coupled to said first electromagnetic wave; and a plurality of slots disposed in said broad wall adjacent to said first slot and coupled to said second electromagnetic wave.

2. A dual band slot antenna comprising a waveguide structure having a broad wall and capable of supporting the propagation of a first electromagnetic wave in a first mode and of a second electromagnetic wave in a mode other than said first mode; source means connected to said structure for launching the electromagnetic waves thereto; a first slot disposed in said broad wall and coupled to said first electromagnetic wave; and a plurality of slots disposed in said broad wall adjacent said first slot and coupled to said second electromagnetic wave.

3. The dual band slot antenna according to claim 2 wherein said first slot is a shunt slot disposed along the center line of said structure and wherein said antenna further includes a probe inserted into said structure adjacent to said first slot.

4. The dual band slot antenna according to claim 2 wherein said first slot is a dielectrically loaded series slot disposed at an angle to the center line of said structure, which center line intersects the center of said slot.

5. The dual band slot antenna according to claim 2 wherein said first slot is a dielectrically loaded shunt slot transversely disposed a predetermined distance from the center line of said structure.

6. The dual band slot antenna according to claim 2 wherein said plurality of slots is arranged in rows equal in number to the specific higher order mode at which said structure supports said second electromagnetic waves, each row of slots including a like number of shunt slots alternately disposed a predetermined transverse distance on either side of a line paralleling the longitudinal center line of said structure, said line being transversely spaced equidistantly from each other and symmetrically about said center line.

7. The dual band slot antenna according to claim 2 wherein said plurality of slots is arranged in rows equal in number to the specific higher order mode at which said structure supports said second electromagnetic waves, each row of slots including a like number of series slots alternately inclined at an angle to a line paralleling the longitudinal center line of said structure, said lines being transversely spaced equidistantly from each other and symmetrically about said center line.

8. A dual band slot antenna comprising a waveguide structure having a broad wall and capable of supporting the propagation of a first electromagnetic wave in a first mode and of a second electromagnetic wave in a mode other than said first mode; terminating means coupled to one end of said waveguide structure and including an end surface orthogonal to the center line of said structure; source means connected to the other end of said waveguide structure and capable of launching said first and second electromagnetic waves onto said structure for propagation therethrough, one of said waves having a frequency within a first band and the other of said waves having a frequency within a second band; a first slot disposed in said broad wall and having a length which is resonant at said first band frequency, the center of said first slot being at a distance from said end surface equal to an odd multiple of quarter-wavelengths of said first electromagnetic wave; and a plurality of slots disposed in said broad wall and each having a length which is resonant at said second band frequency, said plurality of slots being arranged in rows equal in number to the specific higher order mode at which said structure supports said second electromagnetic wave, each row including a like number of shunt slots the centers of which are longitudinally spaced from said end surface by a distance equal to an odd multiple of quarter-wavelengths of said second electromagnetic wave, the slots in each row being alternately displaced a predetermined transverse distance on either side of a line paralleling the center line of said parallelling structure, each of said lines being transversely spaced a predetermined distance from said center line.

9. The dual band slot antenna according to claim 8 wherein said first slot is one of a plurality of longitudinally extending centered slots disposed along said center line at odd multiples of quarter-wavelengths of said first electromagnetic wave and wherein said antenna further includes a probe for each of said centered slots at a pre- of said second electromagnetic wave.

10. The dual band slot antenna according to claim 8 wherein said first slot is one of a plurality of dielectrically loaded series slots disposed at an angle to the center line of said structure and spaced along said center line from said end surface at odd multiples of quarter-wavelengths of said second electromagnetic wave.

11. The dual band slot antenna according to claim 8 wherein said first slot is one of a plurality of dielectrically loaded shunt slots disposed along said center line at even multiples of quarter-wavelengths of said second electromagnetic wave, adjacent ones of said shunt slots being alternately displaced a predetermined transverse distance from said center line.

12. A dual band slot antenna comprising a waveguide structure having a broad wall and capable of supporting the propagation of a first electromagnetic wave in a first mode and of a second electromagnetic wave in a mode other than said first mode; terminating means coupled to one end of said waveguide structure and including an end surface orthogonal to the center line of said structure; source means connected to the other end of said waveguide structure and capable of launching said first and second electromagnetic waves onto said structure for propagation therethrough, one of said waves having a frequency within a first band and the other of said waves having a frequency within a second band; a first slot disposed in said broad wall and having a length which is resonant at said first band frequency, the center of said first slot being at a distance from said end surface equal to an odd multiple of quarter-wavelengths of said first electromagnetic wave; and a plurality of slots disposed in said broad wall and each having a length which is resonant at said second band frequency, said plurality of slots being arranged in rows equal in number to the specific higher order mode at which said structure supports said second electromagnetic wave, each row including a like number of series slots the centers of which are longitudinally spaced from said end surface by a distance equal to an even multiple of quarter-wavelengths of said second electromagnetic wave, the slots in each row being alternately inclined at an angle to a line paralleling the center line of said paralleling structure, each of said lines being transversely spaced a predetermined distance from each other and symmetrically about said center line.

13. The dual band slot antenna according to claim 12 wherein said first slot is one of a plurality of longitudinal

extending centered slots disposed along said center line at odd multiples of quarter-wavelengths of said first electromagnetic wave and wherein said antenna further includes a probe for each of said centered slots disposed in said structure on alternate sides of said centered slots at a predetermined transverse distance therefrom.

14. The dual band slot antenna according to claim **12** wherein said first slot is one of a plurality of dielectrically loaded series slots disposed at an angle to the center line of said structure and spaced along said center line from said end surface at odd multiples of quarter-wavelengths of said electromagnetic wave.

15. The dual band slot antenna according to claim **12** wherein said first slot is one of a plurality of dielectrically loaded shunt slots disposed along said center line at even multiples of quarter-wavelengths of said second electromagnetic wave, adjacent ones of said shunt slots being alternately displaced a predetermined transverse distance from said center line.

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